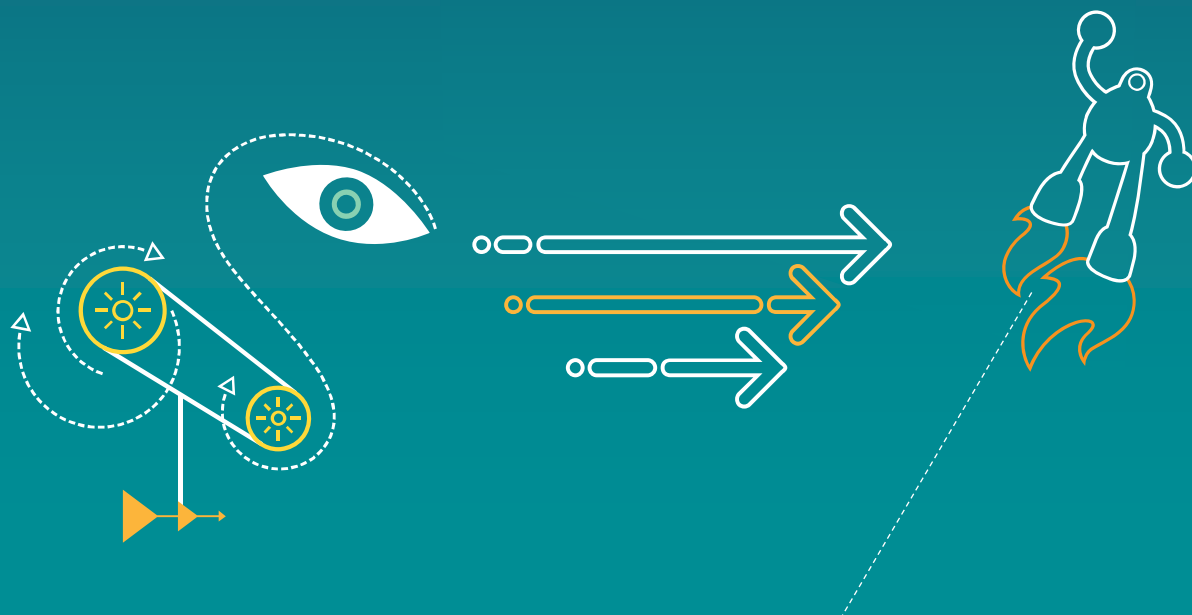


Mike Stauffer, Qualcomm Atheros
August 10, 2014

Connecting the Internet of Everything



1

What Do We Mean by
The Internet of
Everything (IoE)

2

Connected Home
Ecosystem –
context for IoE in the
Smart/Connected Home

3

Key Smart Home connectivity
technologies
(802.11abgn/ac/ah, 802.15.4,
Bluetooth/BLE, Z-Wave, PLC)
- Key general connectivity
characteristics
- Technology comparison overview
- Deeper dive into 802.11ah, a new
technology for IoE
- Technology-Application Matching

Agenda

The Internet of Everything (IoE) is here

Massive surge in connected things has already begun

25B

permanently connected things by 2020*

Over half of these devices will be non-handsets



Lights



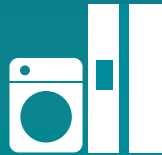
Speakers



PEV



Security
Cameras



Home
Appliances

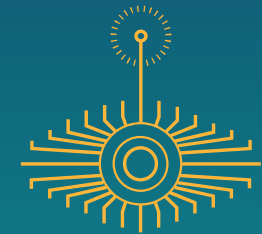
Smarter



2x Connected devices
in household by 2020

1000x Anticipated data
traffic growth
driven by more
connection and
richer content

More
connected



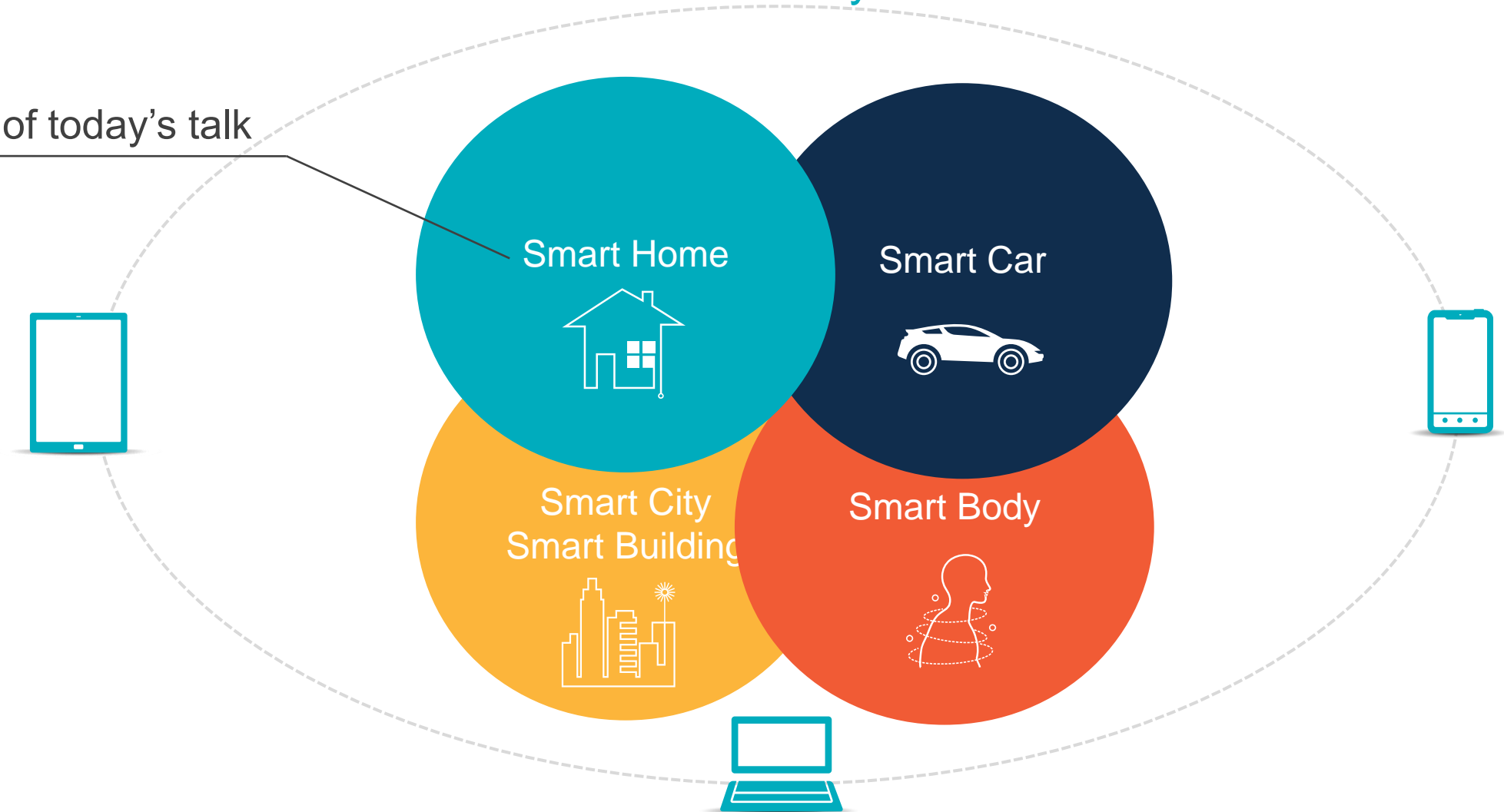
~75% US 18-24 year olds
reach for
smartphone immediately
after waking up

~7B Cumulative smartphone
sales estimated 2013-
2017

IoE – A Set of Smart Ecosystems

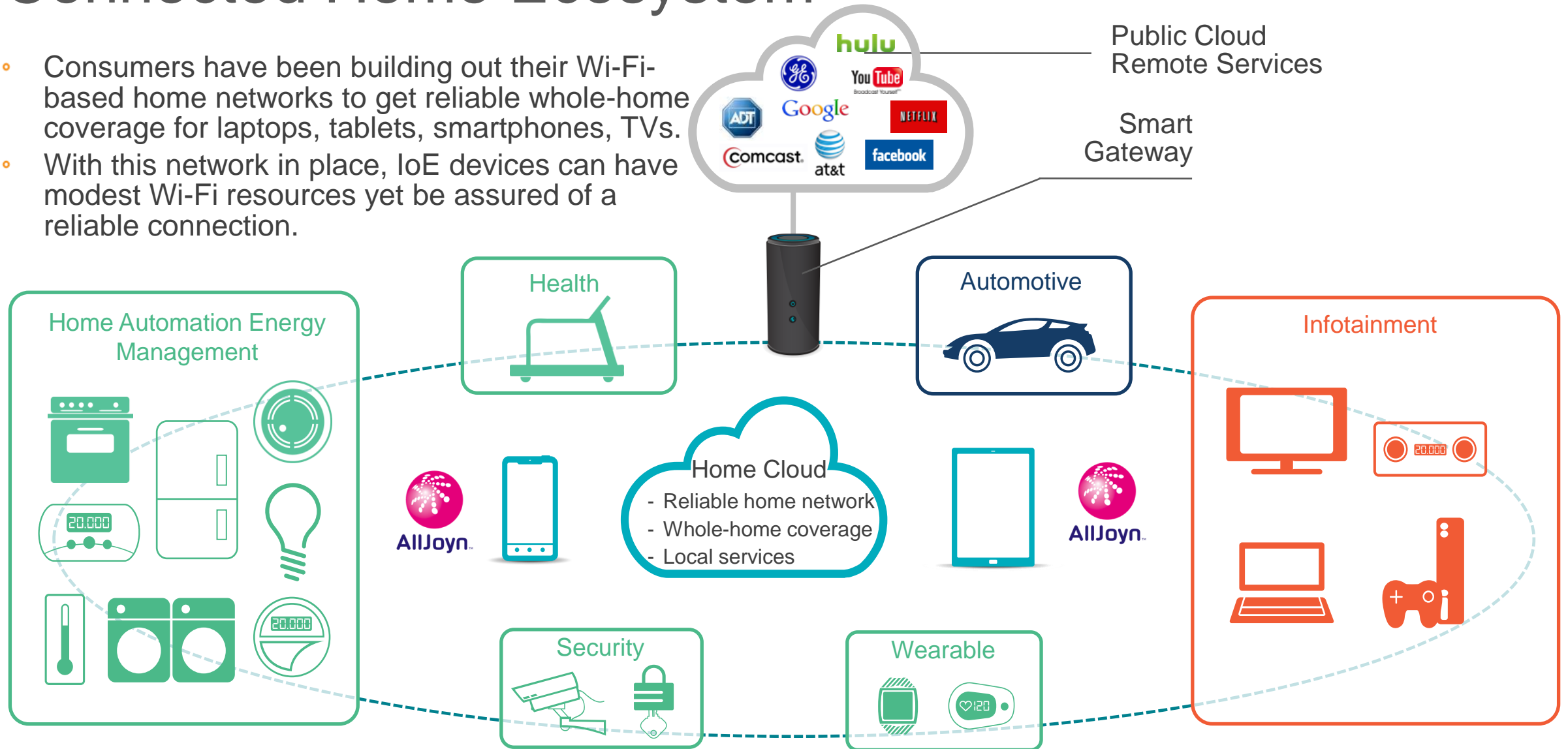
Personal Mobile Devices Used Across Ecosystems

Focus of today's talk



Connected Home Ecosystem

- Consumers have been building out their Wi-Fi-based home networks to get reliable whole-home coverage for laptops, tablets, smartphones, TVs.
- With this network in place, IoE devices can have modest Wi-Fi resources yet be assured of a reliable connection.



Reliable Whole-Home Coverage Needed for IoE



- 1) Insufficient Wi-Fi coverage far from gateway for laptop/tablet/phone/TV Internet access

Reliable Whole-Home Coverage: Range Extenders



- 1) Insufficient Wi-Fi coverage far from gateway for laptop/tablet/phone/TV Internet access
- 2) Consumer installs Wi-Fi or PLC/Wi-Fi extenders to solve laptop/TV access problem

Reliable Whole-Home Coverage: IoE Devices Benefit



- 1) Insufficient Wi-Fi coverage far from gateway for laptop/tablet/phone/TV Internet access
- 2) Consumer installs WiF or PLC/Wi-Fi extenders to solve laptop/TV access problem
- 3) With good whole-home coverage, new IoE devices can easily connect, with simple, low Tx power connectivity

Smart Gateway Contains & Bridges All PHYs

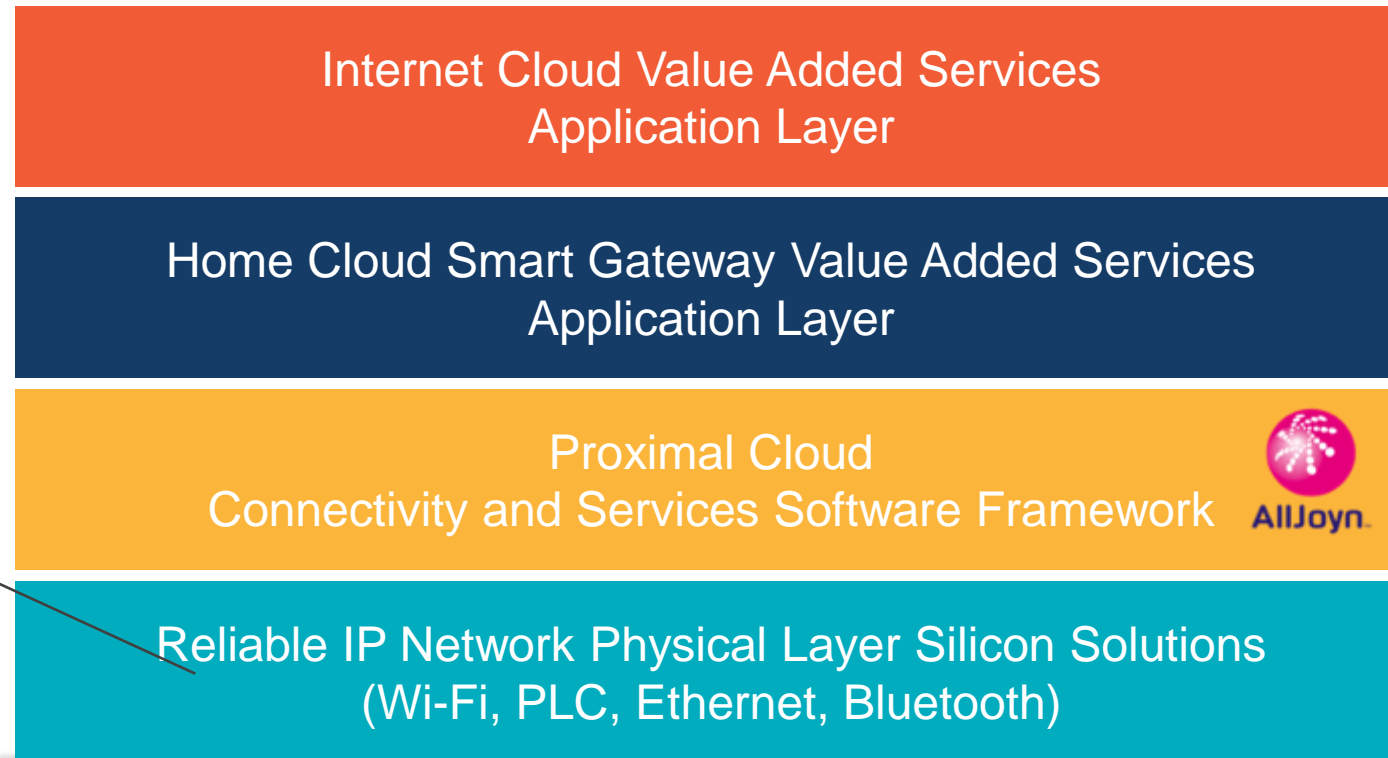


Connectivity Technology **A**

Connectivity Technology **B**

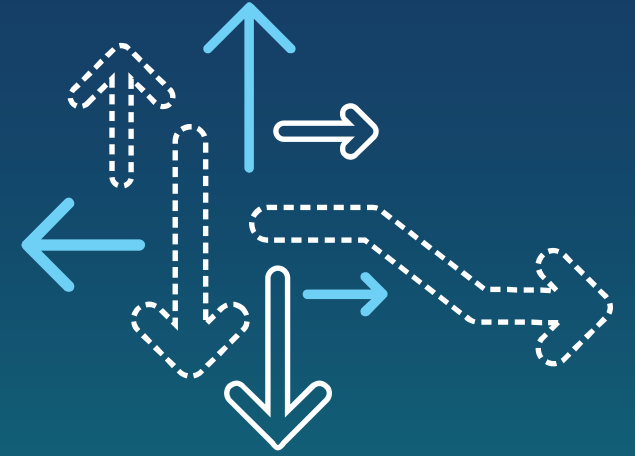
Connectivity Technology **C**

IoE Connected Home Ecosystem Layers



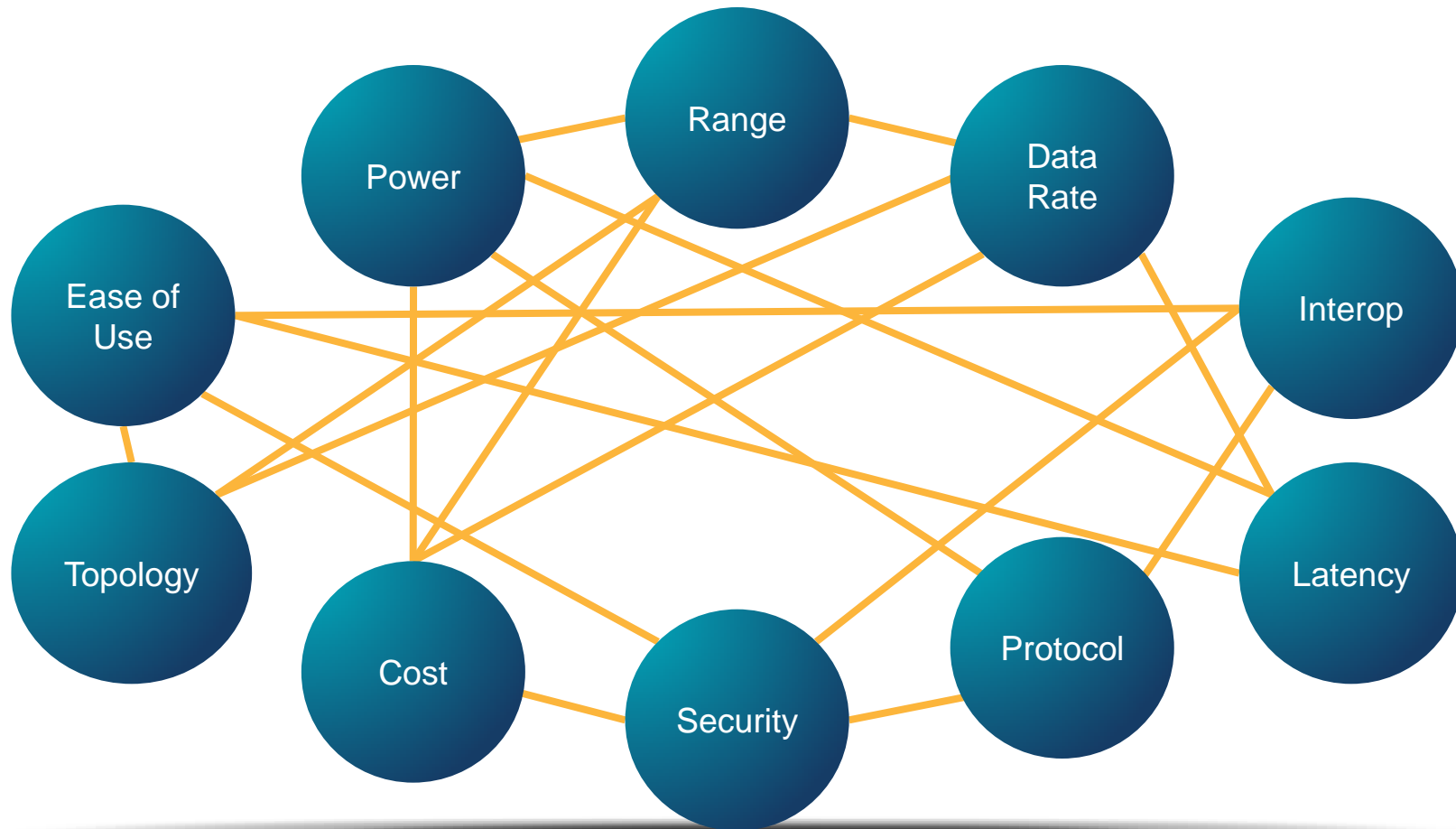
Focus of today's talk

IoE Connectivity PHY Technology Characteristics



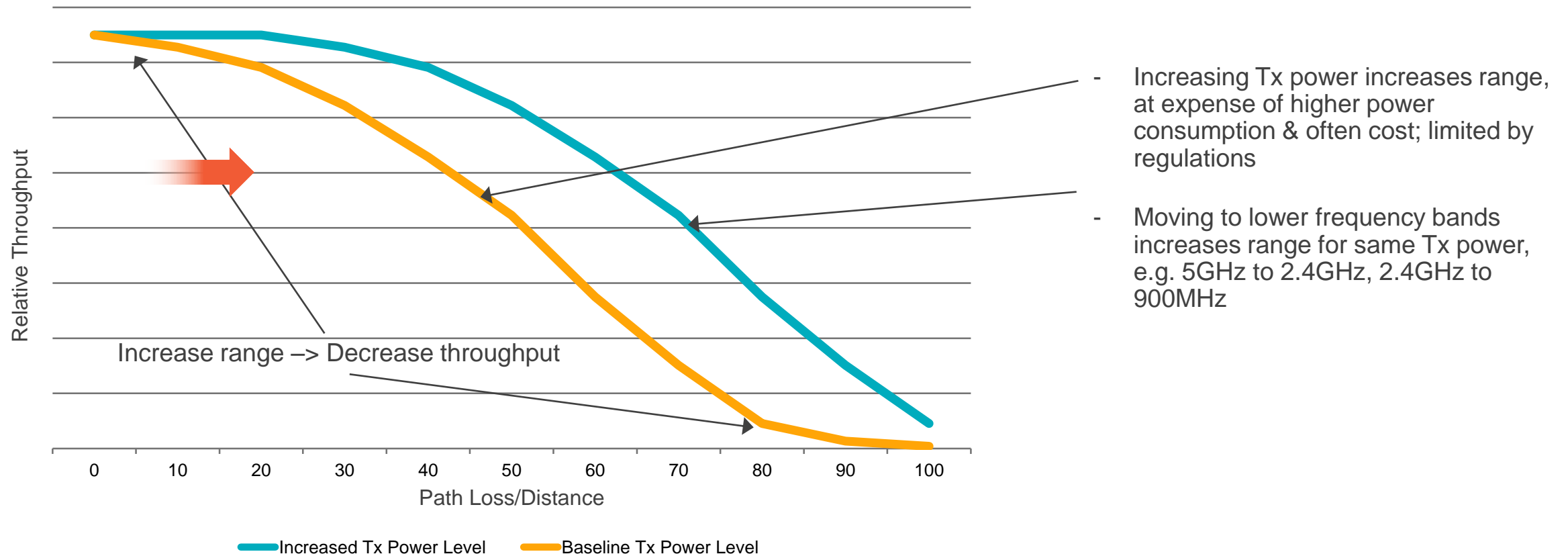
IoE PHY Characteristics

Characteristics interact, requiring tradeoffs to match application requirements



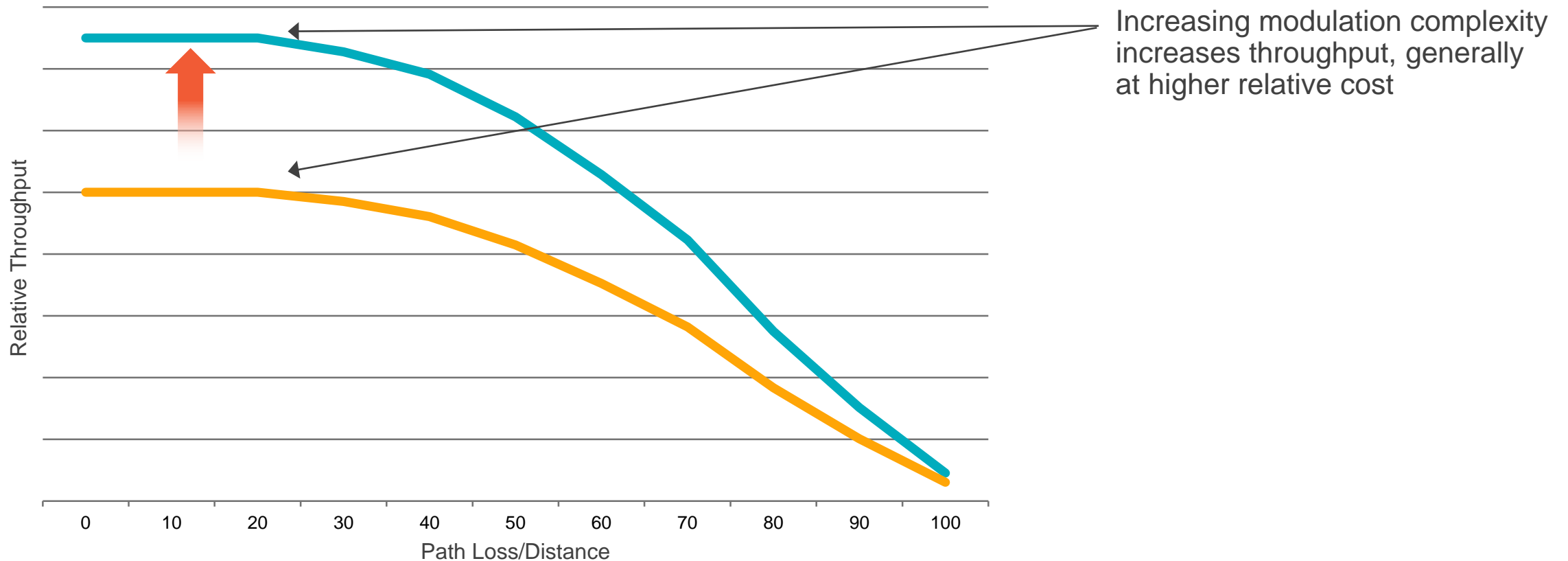
Characteristics Tradeoff Example

Throughput vs. Range, Tx Power vs. Range/Throughput







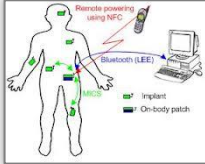
Characteristics Tradeoff Examples

Modulation Complexity vs. Throughput



Power Consumption

Match connectivity solution to the power source

Power Source	Energy Capacity	Typical Device
Line Powered	Several amps	
Battery Powered		
Rechargeable	1300mAh	
AA	2000mAh	
AAA	1200mAh	
Coin Cell	200mAh	
Energy Harvesting	Solar: ~10uA Temp Diff.: ~600uW Mechanical: ~100uJoule	

User acceptable
recharge/replace cycle

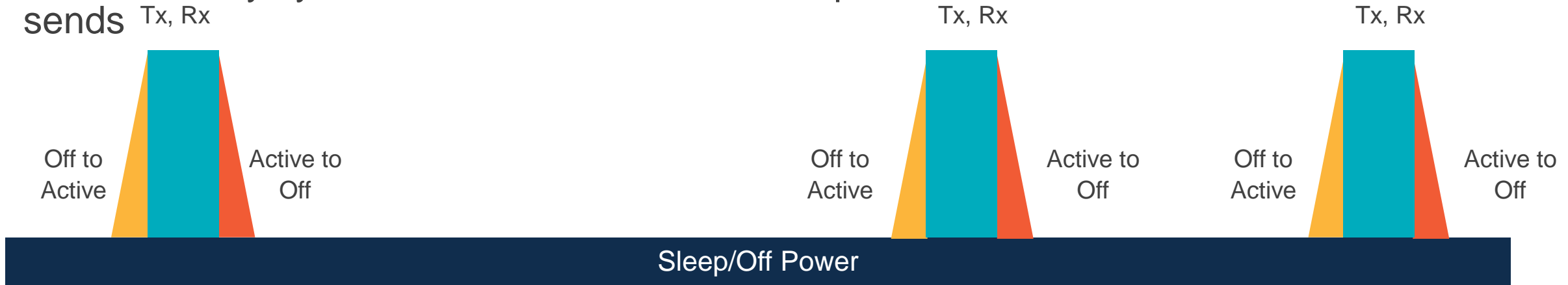
EVERY DAY

EVERY YEAR

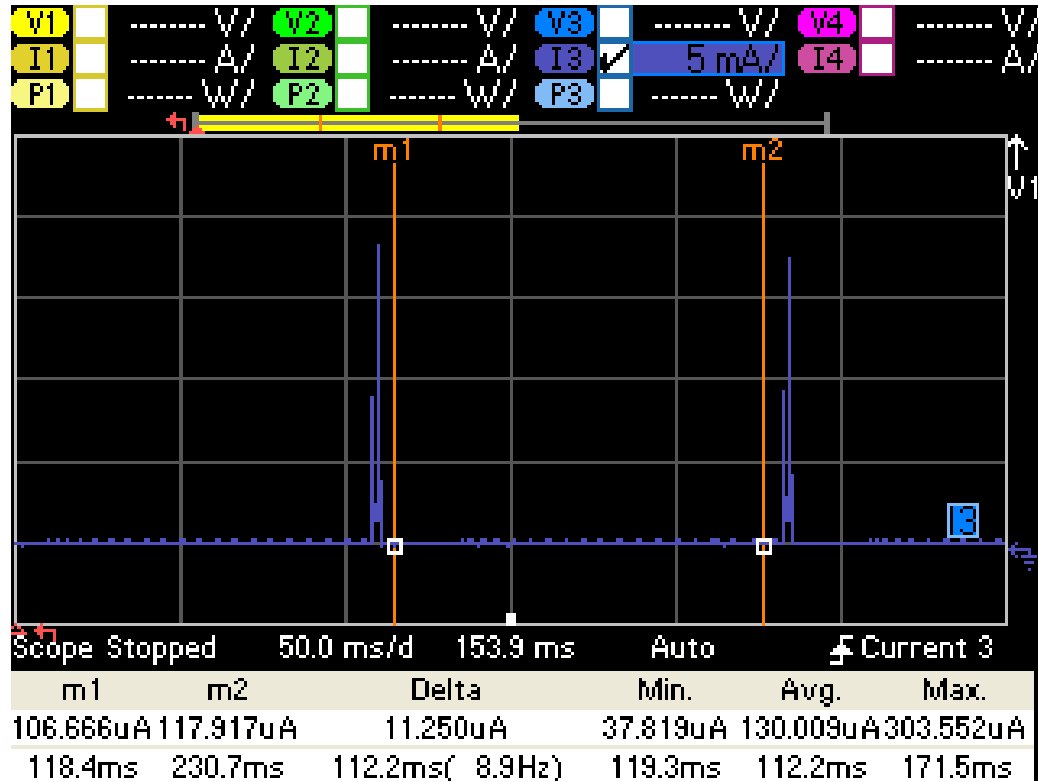
Power Consumption

Key Influences

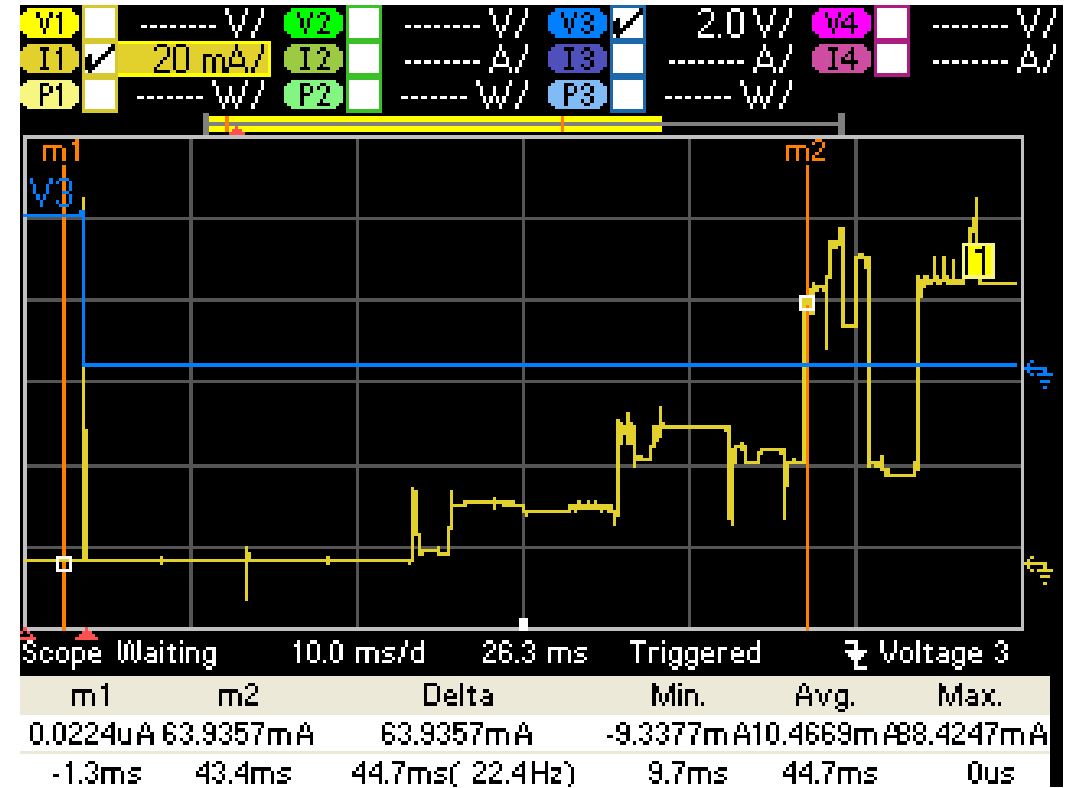
- Connectivity technology parameters
 - Tx power, Rx power, sleep power
 - Protocol packet size/header overhead (shorter packet headers require less Tx time)
 - Protocol allows device to sleep a long time (power), with fast wakeup from sleep to send packets (latency)
 - PHY data rate while sending packet (faster bits are transmitted, less time Tx power amp is on)
- Environment - channel interference & traffic congestion (retries use more power)
- Use case duty cycle - how often device wakes up to Tx/Rx data & how much data it sends



Wi-Fi Low Energy Consumption Example



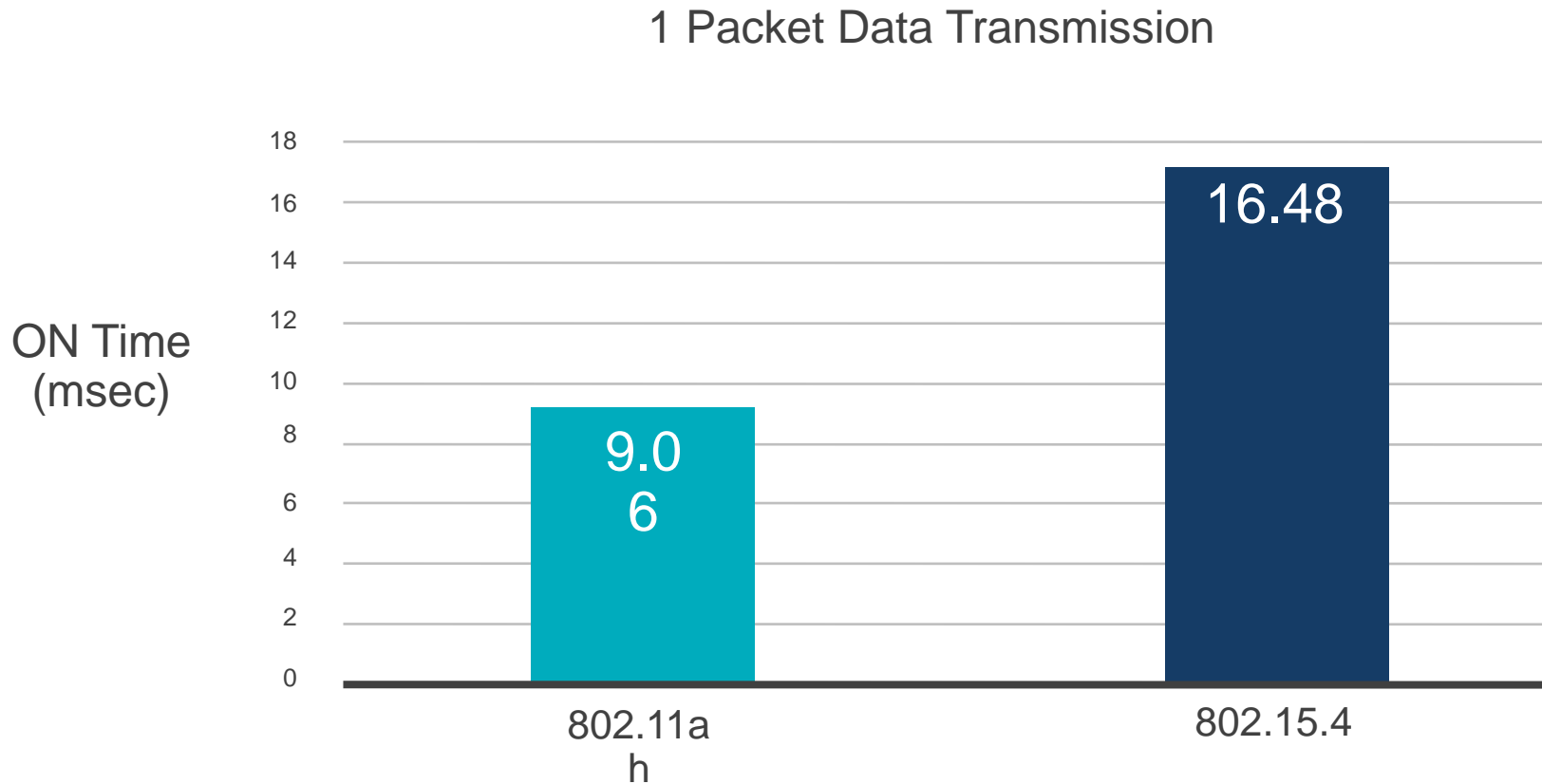
IEEE Network Sleep – always connected
130uA @ Sleep state
2 msec to beacon reception ready



Off to Active
< 1uA on board @ Off state
40 msec to device operational

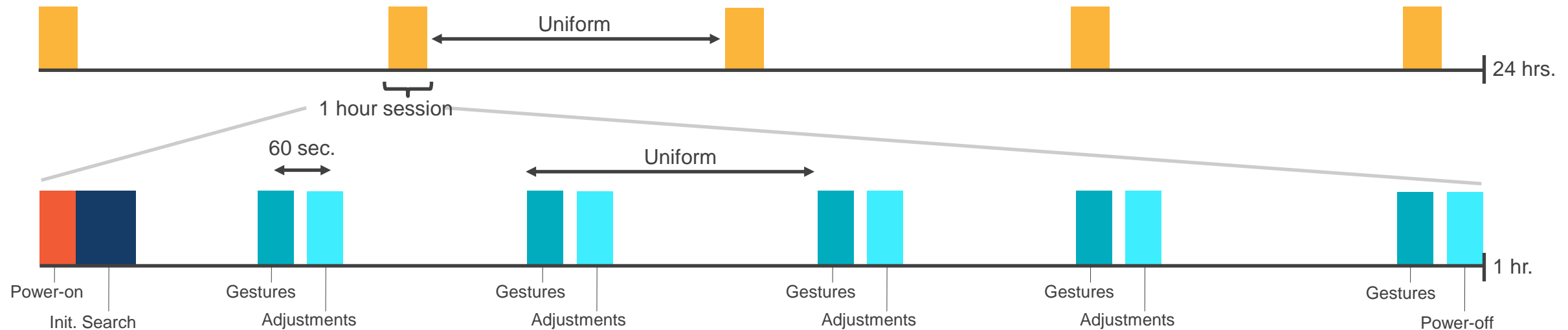
Higher Data Rate Can Reduce Power Consumption

Higher data rate results in less Tx ON time to send same size packet



Protocol Adjustments to Match App Can Reduce Power

Remote Control Usage Model & Power Consumption



- Power model based on custom protocol and specific chip properties
- Protocol implemented at both ends, e.g. TV & RC
- User has 5 TV watching sessions of 1 hour each per day
- Each TV watching session commences with a power-on sequence
- Each TV watching session involves user changing channels 10 times with switch interval of 5 secs between channel switches before converging to desired channel
- During the session, user adjusts the settings of the TV up to 5 times - each setting involves pressing 5 button pushes on the RC
- During the session, user performs 5 instances of voice commands and gestures of 5 seconds each

Battery Life

2xAA	2xAAA
12.43 Months	6.73 Months

Security

Security will be a key issue for successful IoE device deployment

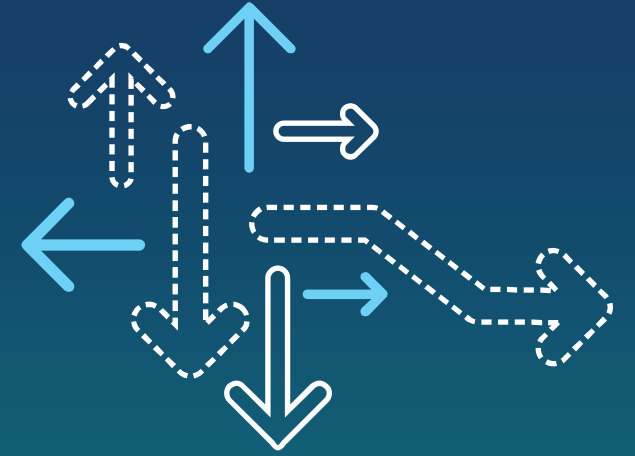


EYES OF A
STRANGER

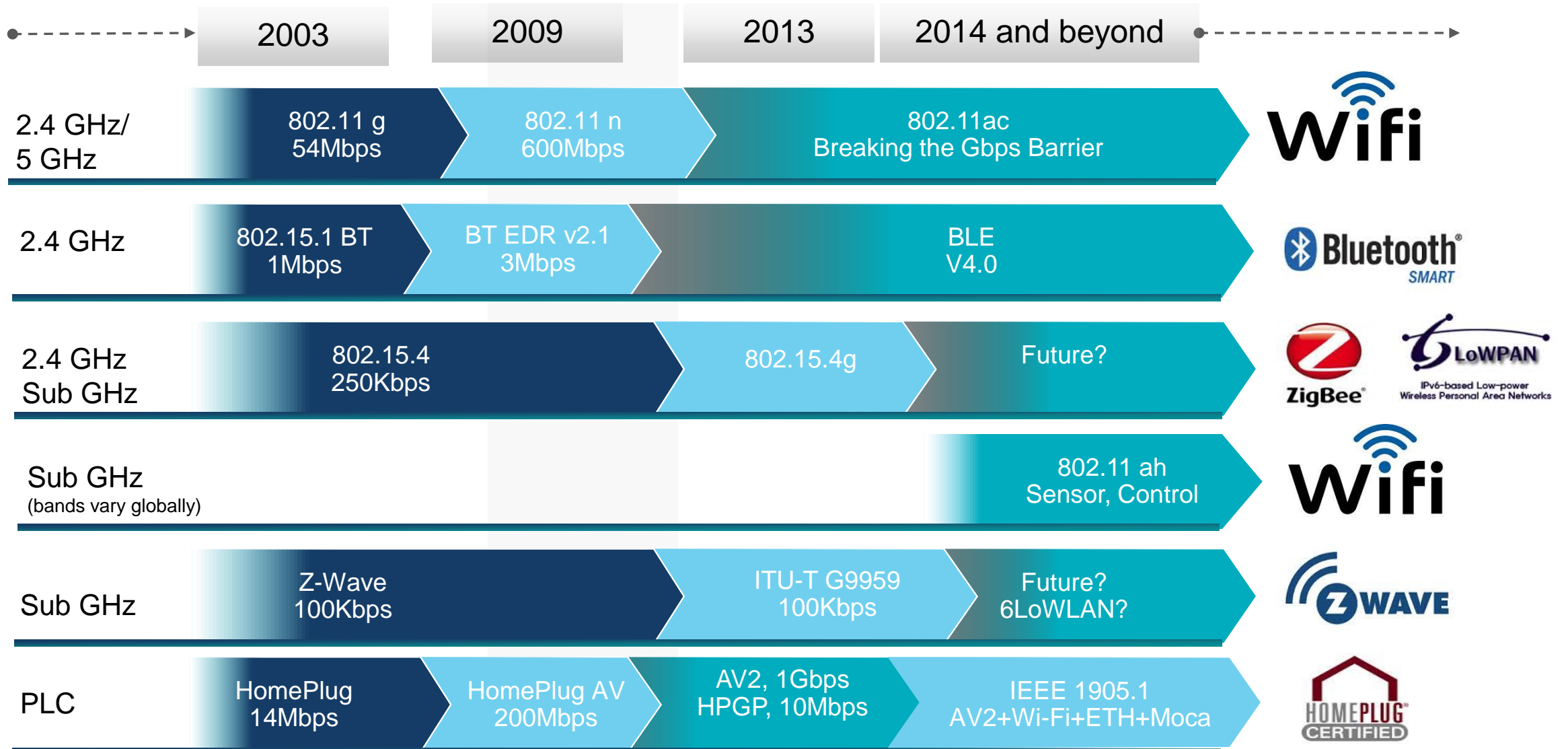
Baby Monitor Hacked

- Consumers must trust their privacy is protected
- Security must be dealt with throughout the IoE value chain/stack
- Tradeoffs between security & ease-of-use
- PHYs provide mechanisms to enable security over the channel
 - 128-bit AES encryption
 - Secure onboarding protocols, with device authorization & authentication
 - Secure device SW & SW updates

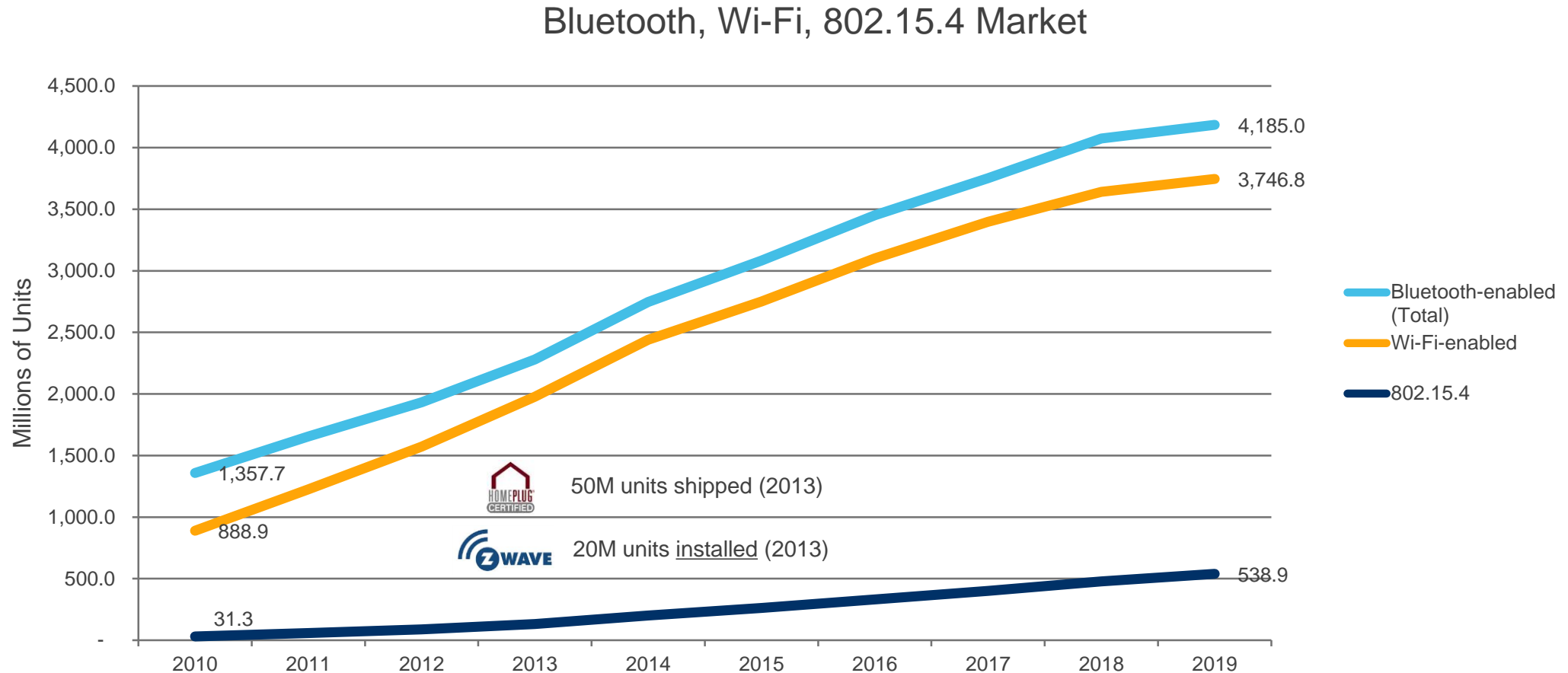
Key IoE Connectivity PHY Technologies



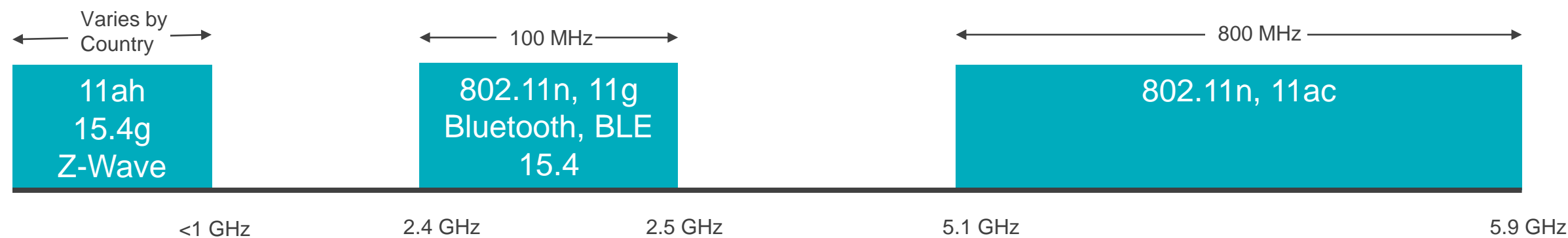
Key IoE PHY Technologies



What's Happening in the Market?



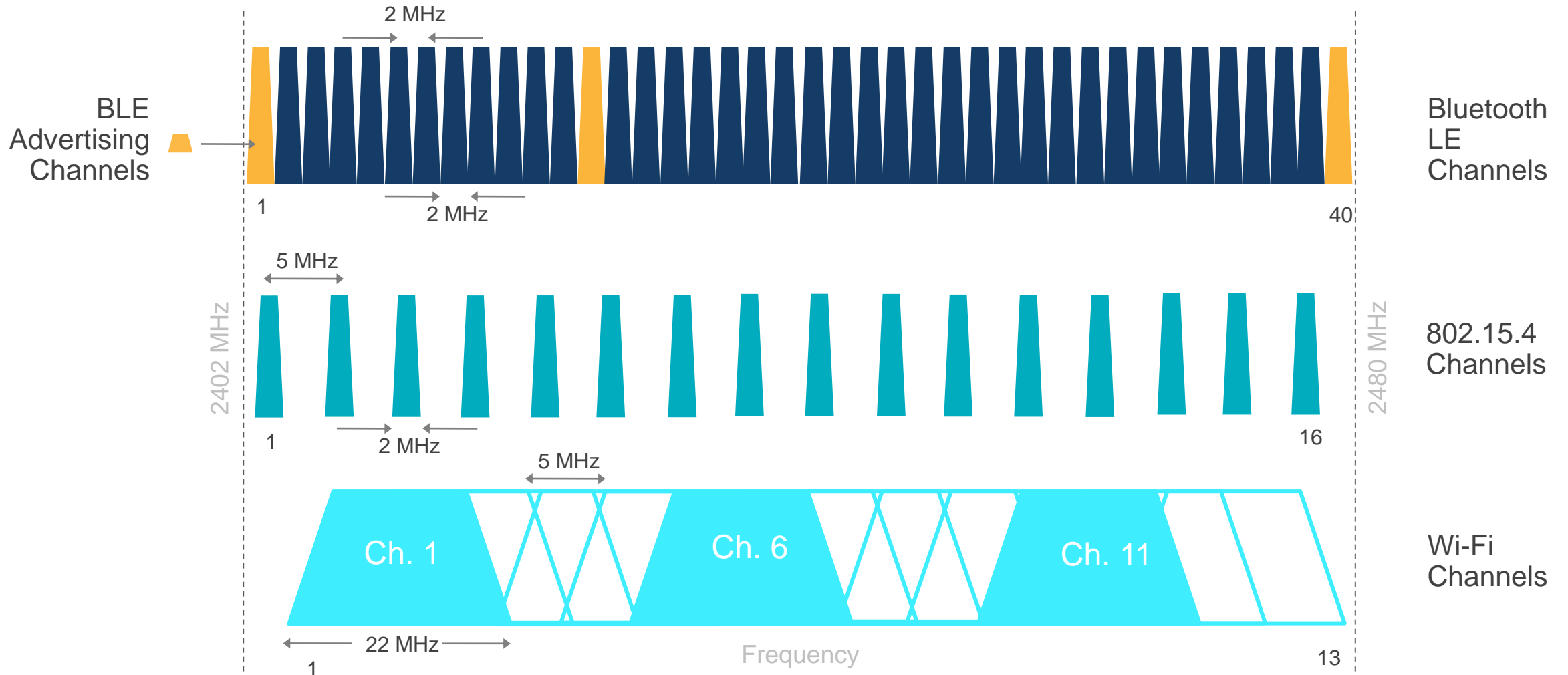
IoE Wireless PHY Spectrum



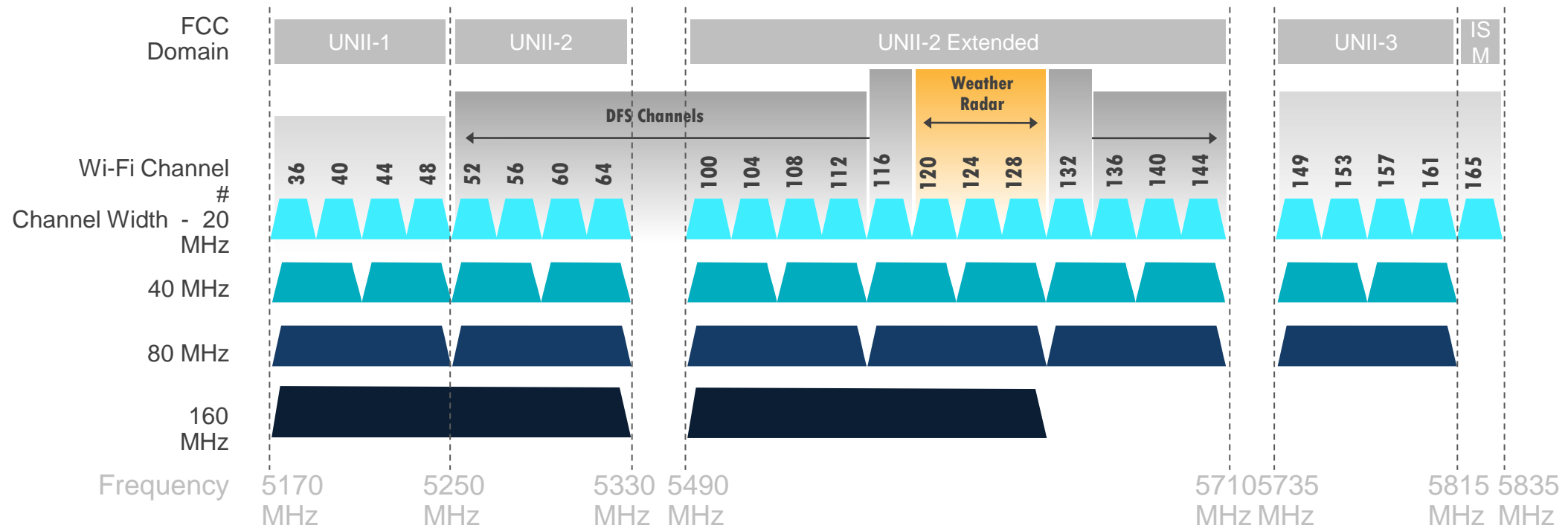
	<1GHz	2.4GHz	5GHz
Range	Best for given Tx power		
Spectrum Size			
Congestion/Coexistence	Early market		Lots of spectrum, clean air
Harmonized Spectrum	Varies by country		

IoE Wireless 2.4GHz Band Channelization

2.4GHz Coexistence – 802.11abgn, Bluetooth Low Energy, 802.15.4



802.11a/11n/11ac Spectrum Channelization – 5GHz Band



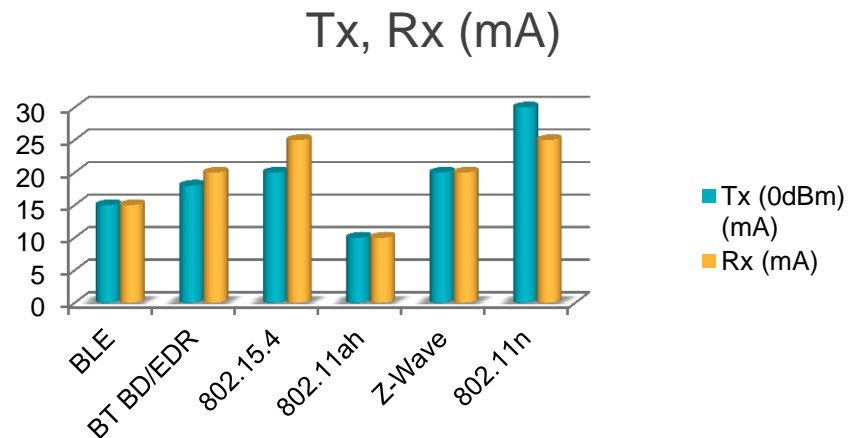
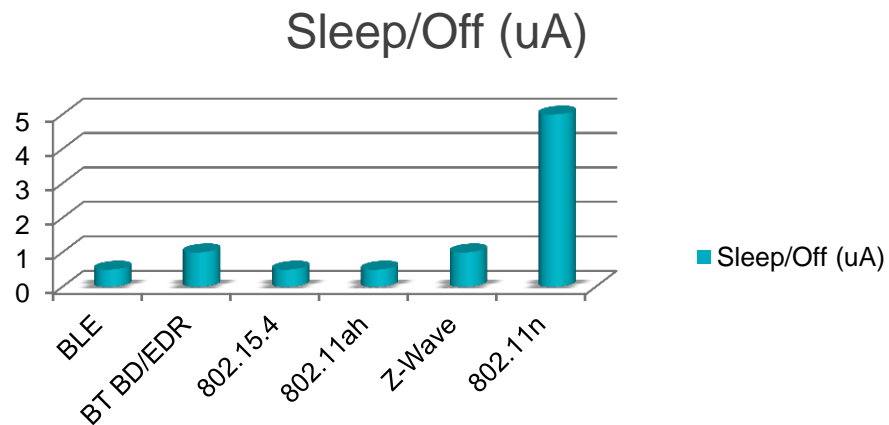
*Channels 116 and 132 are Doppler Radar channels that may be used in some cases

IoE Connectivity Technology Comparison

PHY	Freq. Band	Coverage/Range	PHY Data Rate (max)	Spectrum Harmonization
802.11n 1x1 (2.4GHz)	2.4GHz	Whole house, repeaters may be needed	75Mbps	Yes
Bluetooth BR/EDR	2.4GHz	Short range, in-room	3Mbps	Yes
Bluetooth Low Energy	2.4GHz	Short range, in-room	1Mbps	Yes
802.15.4	2.4GHz	Whole-house, with mesh	250Kbps	Yes
802.15.4g	<1GHz	~+10dBm better than 2.4GHz	250Kbps	Varies WW
802.11ah	<1GHz	~+10dBm better than 2.4GHz Whole house, multi-hop	4Mbps (1x1, 1MHz ch.)	Varies WW
Z-Wave	<1GHz	~+10dBm better than 2.4GHz Whole house with mesh	100Kbps	Varies WW
HPGP	28MHz	Whole house	10Mbps	Yes

IoE Wireless Connectivity Technology: Power Consumption

Combination of basic silicon power consumption, protocol efficiency and use cases determine overall power consumption.

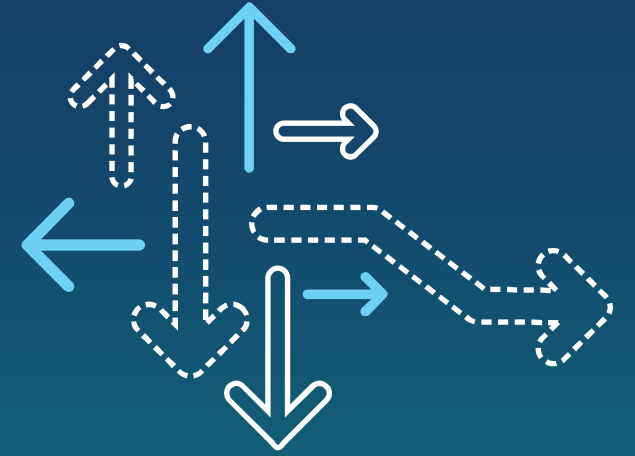


PHY	Protocol Efficiency			
	MAC HDR (bytes)	PHY ON (relative)	State/Control	Stream
802.11n 1x1 (2.4GHz)	30	Short	N	Y
Bluetooth BR/EDR	8	Med-Long	Y	Audio
Bluetooth Low Energy	5	Med-Long	Y	N
802.15.4	23	Long	Y	N
802.15.4g	23	Long	Y	N
802.11ah	18	Short	Y	Y
Z-Wave	9	Long	Y	N
HPGP	Due to line power, power consumption not critical			

IoE Connectivity Technology Comparison (3)

PHY	Interoperability	IP Connectivity	Network Scalable
802.11n 1x1 (2.4GHz)	WFA cert.	Native IP	256 STA, bridging to multiple APs
Bluetooth BR/EDR	BT SIG cert.	BNEP/6LoWPAN	7 in piconet, scatternets
Bluetooth Low Energy	BT SIG cert.	6LoWPAN/Gateway	Billion
802.15.4	ZigBee	6LoWPAN	>1000, low data rate limits mesh size
802.15.4g		6LoWPAN	>1000, low data rate limits mesh size
802.11ah	WFA cert.	Native IP	>8000
Z-Wave	1or 2 vendors	6LoWPAN	232 nodes/controller
HPGP	HPA	Native IP	100s

802.11ah – New Technology for IoT



802.11ah – 3rd Band Wi-Fi

802.11g
2.4 GHz

802.11n
2.4 & 5 GHz

802.11ac
5 GHz

802.11ah
(sub 1 GHz)

Wi-Fi ecosystem

WFA certified interoperability and Wi-Fi user experience

Improved Range

10 dB link budget advantage over 2.4 GHz technologies (>50% longer distance @same Tx power)

Low Power

Supports multi-year battery life sensor operation

Rich Data Rates

150Kbit/s ~ 78 Mbits/s per spatial stream (sensor, audio, security camera, internet)

Scalable

Support thousands of nodes

IP connectivity

Same as Wi-Fi

Outdoor Coverage

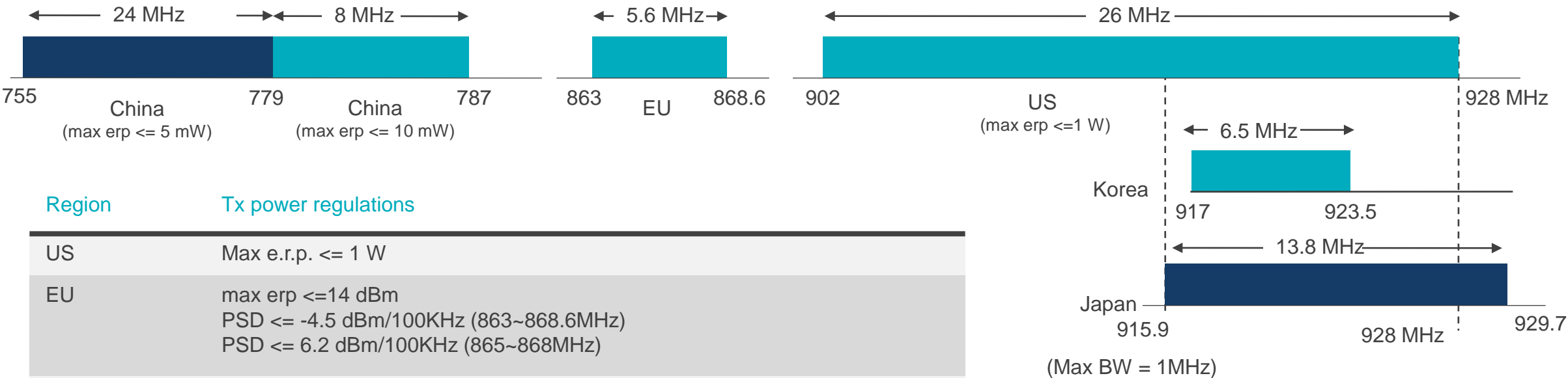
Support for larger delay and Doppler spreads, support for relays

802.11ah Specifications

Frequency Bands	470-510MHz, 755-787MHz, 863-869MHz, 902-928MHz, 510-755MHz (UHF, optional)
Channelization	902-928MHz (BW/#ch.): 1MHz/26, 2MHz/13, 5MHz/6, 8MHz/3, 16MHz/1
Modulation	OFDM with BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM
PHY Rates (Throughput)	Up to 78Mbps (1x1, 16MHz ch.); up to 4Mbps (1x1, 1MHz ch.)
Media Access Mechanism	CSMA/CA (carrier sense multiple access/collision avoidance)
Range	>10dB link budget advantage over 2.4GHz technologies => double the range @same Tx power or 10x Tx power reduction to reach same range Single and Multi-Hop relay for range extension
Topology	Infrastructure, ad hoc, multi-hop
Protocol Efficiency (frame size, etc.)	MAC Header size: 18 bytes, Short ON time due to higher data rate, Short frames (header, ACK/BA), Optimized paging: short beacon, unicast paging with very short NDP frame, Target Wake Time for efficient wakeup, no beacon checking, Beaconless mode (STA wakeup any time , poll for data, no synchronization), Long sleep time without re-association
Sleep/Suspend Power Consumption/ Latency (sleep to packet transmit)	Low power consumption provides months to years on a battery. Suspend state <2uA @ 3.3V, <10ms IEEE PS sleep <15uA @ 3.3V, <1ms Sleep power at reset <0.5uA @ 3.3V
Active Power Consumption	Tx <25mA @ +6dBm (60mW), <10mA @0dBm (45mW), @3.3V Rx <10mA @ 3.3V
Security	128-bit AES
Interoperability	WFA certification
Robustness, complexity, cost	

Harmonized 11ah Spectrum in Key Geographies

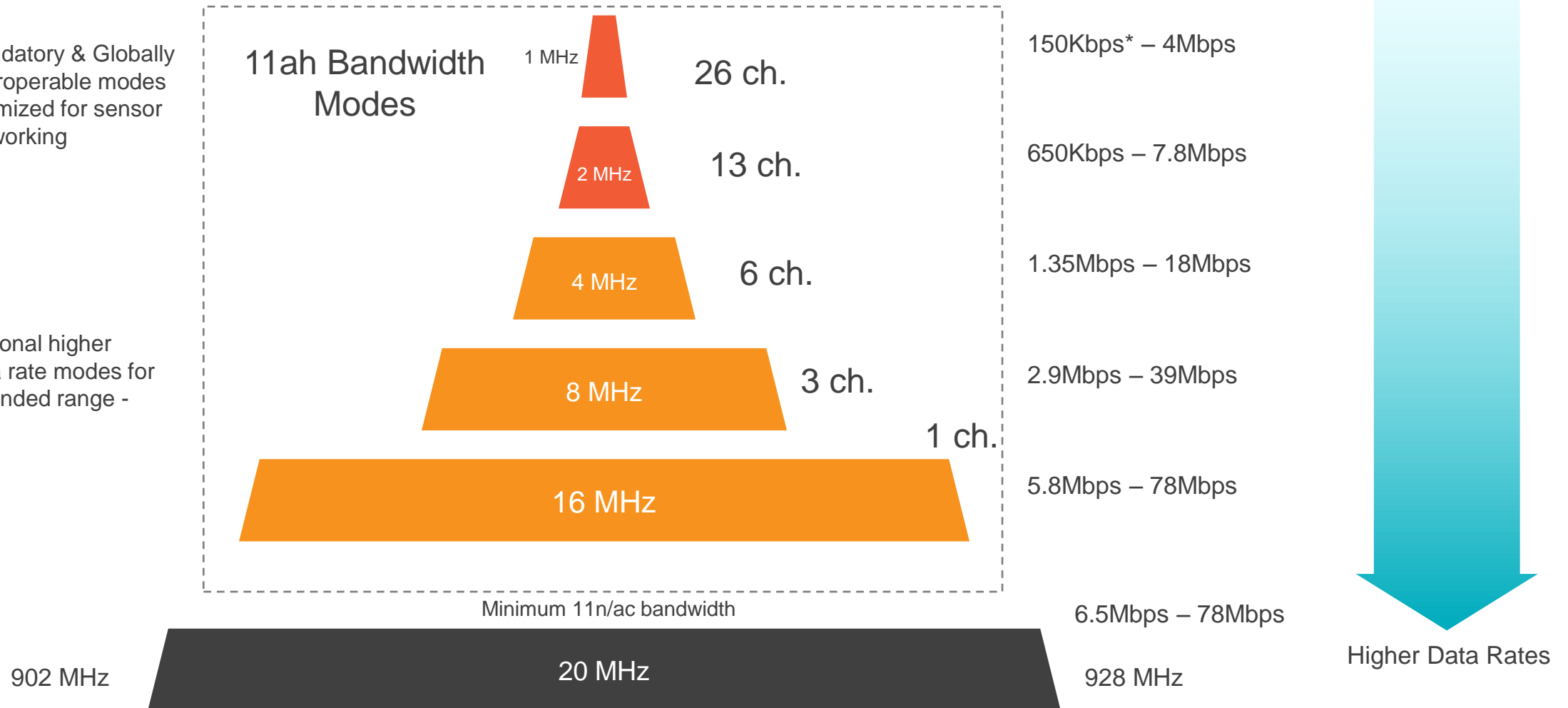
All Bands are Sub-1 GHz



Rich Data Set Enables both IoE (sensors) and Extended Range Wi-Fi Applications

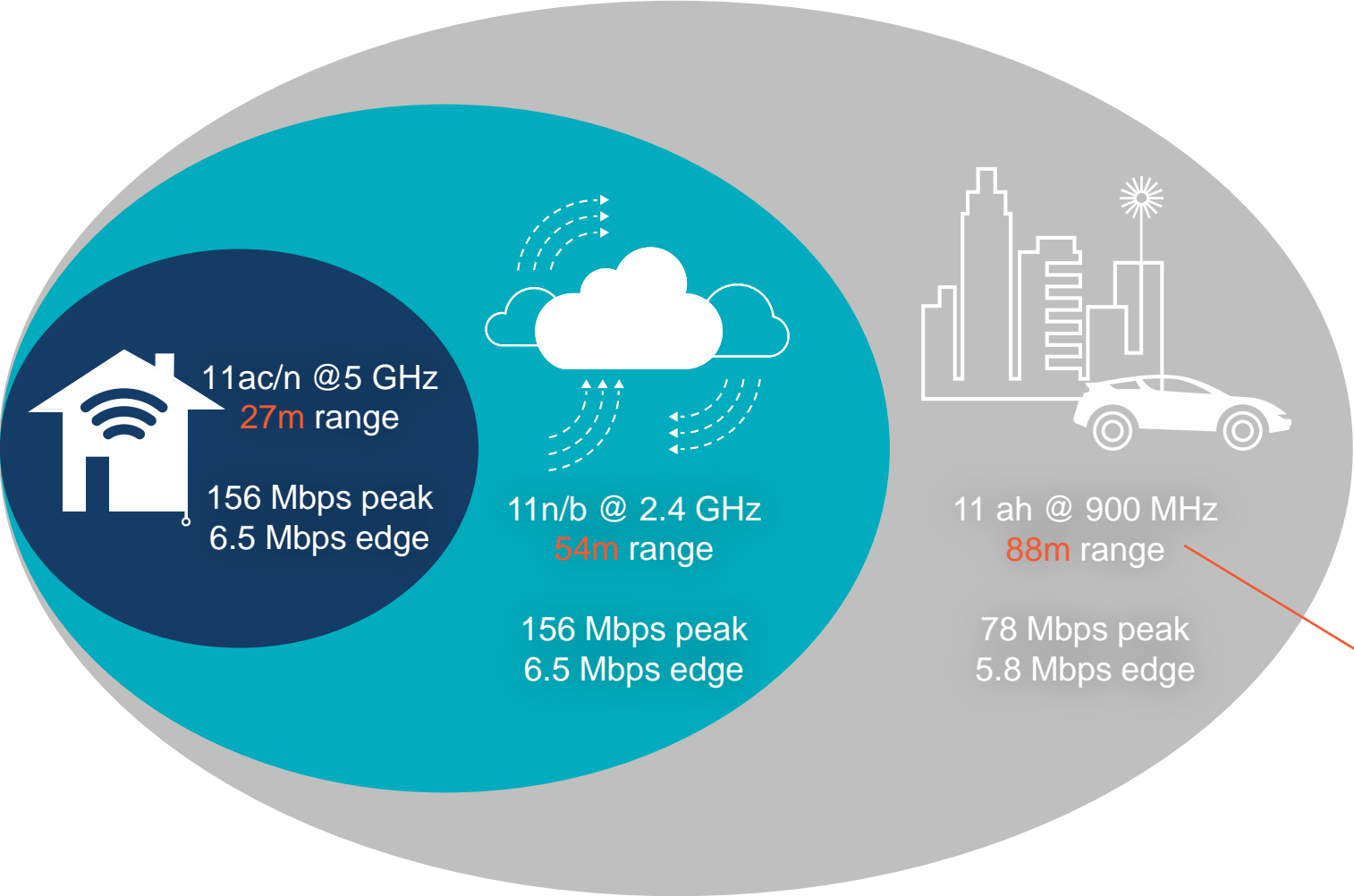
Mandatory & Globally Interoperable modes optimized for sensor networking

Optional higher data rate modes for extended range -



* Single spatial stream rates shown. 150Kbps achieved via a new repetition modulation and coding scheme (MCS10)

802.11ah Provides Extended Range vs. Legacy Wi-Fi*

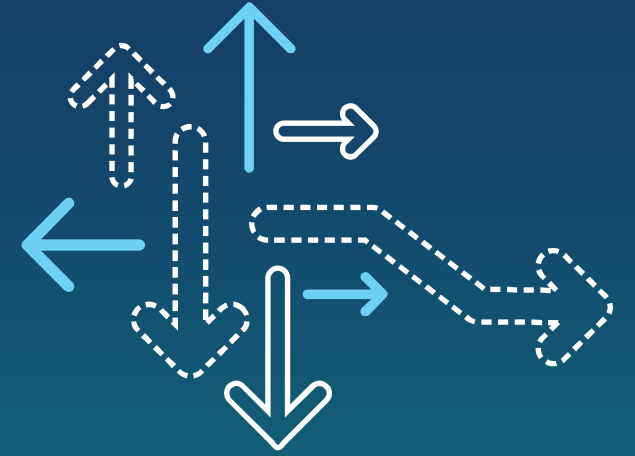


	Peak Rate Mbps 2 SS MIMO	Edge Rate Mbps (Range)	Tx x Rx
11ac/n 5 GHz 20 MHz BW 40 MHz BW	156 360	6.5 (27m)	3x2
11n/b 2.4 GHz 20 MHz BW	156	6.5 (54m)	3x2
11ah 900 MHz 8 MHz BW (US Only)	78	5.9 (88m)	2x2

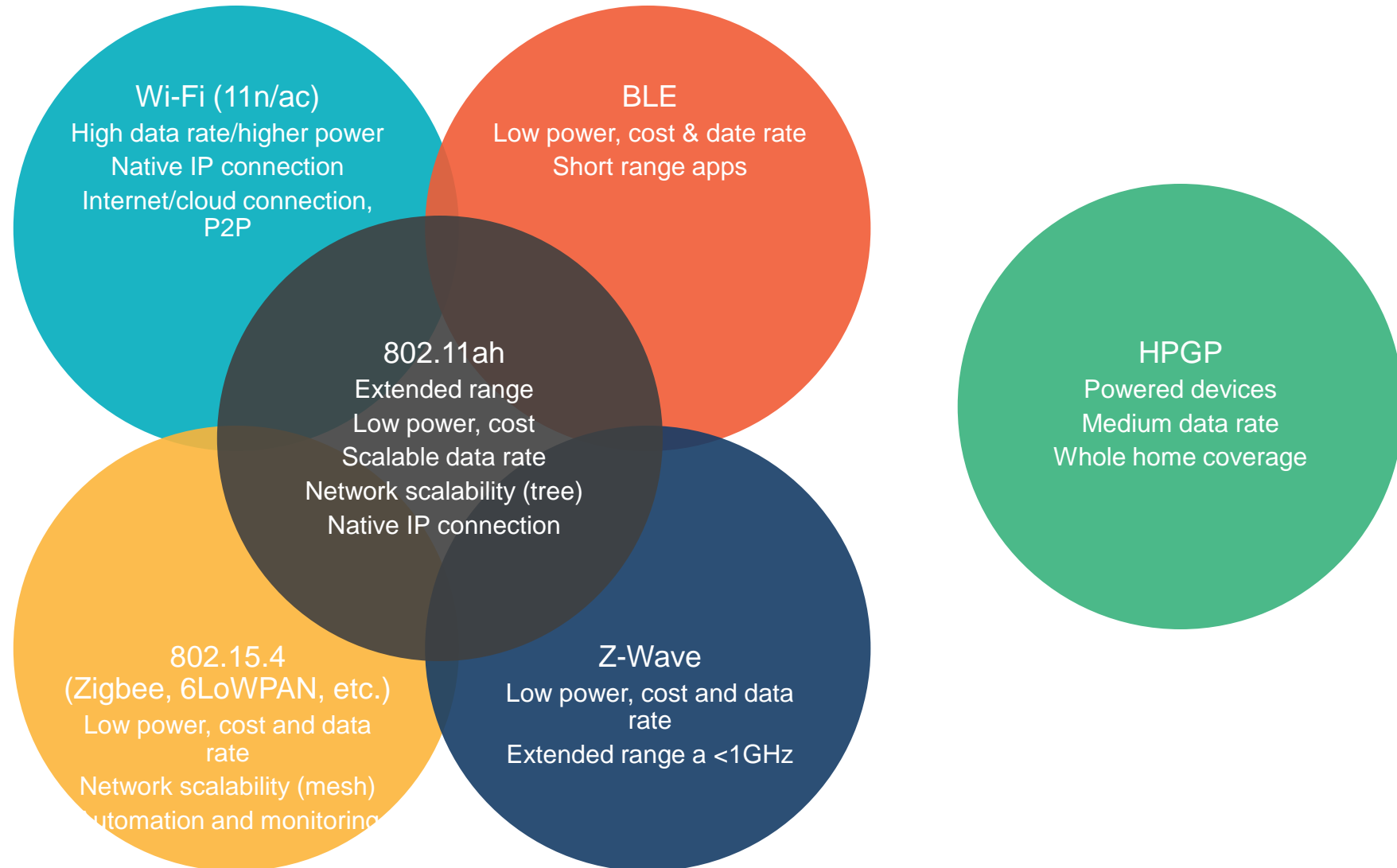
Smartphones, Tablets,
Laptops can be used in
Garages, Backyards, and
Streets

*US has 26MHz spectrum in 900 MHz available. Simulation Assumptions: Minimum QoS 5Mbps, Retail AP, 21 dBm/Tx chain Tx power, Indoor to outdoor (d^4) channel model

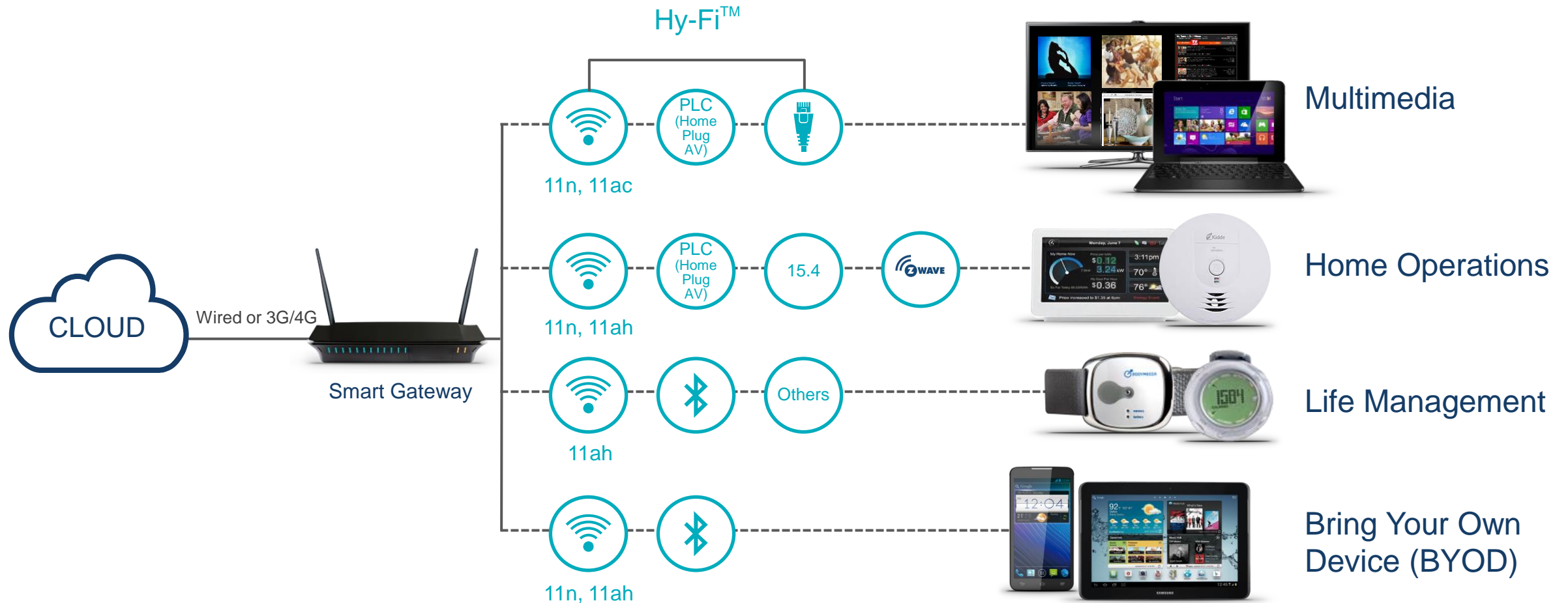
And Finally ... Where Are These PHYs Used?



IoE Connectivity Technology Qualitative Comparison



IoE Connectivity Technology Application Match



Thank you

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